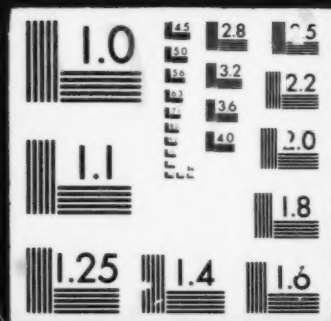


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BARR LAKE AND ITS ODOR RELATIONSHIPS

Robert O. Sylvester

Public Health Service
Denver, Colorado

December 1965

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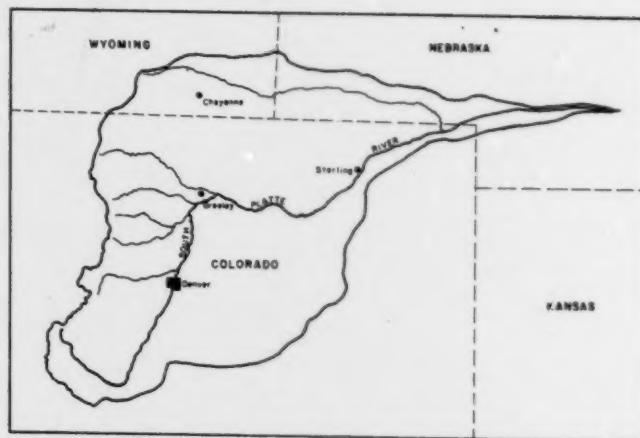
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BARR LAKE AND ITS ODOR RELATIONSHIPS



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE, REGION VIII
DENVER, COLORADO

DECEMBER 1965

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Report (PR-no.)

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BARR LAKE AND ITS ODOR RELATIONSHIPS

**U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Region VIII
Denver, Colorado**

**Robert O. Sylvester
University of Washington
Sanitary Engineer Consultant
and
South Platte River Basin Project
Denver, Colorado**

December 1965

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SOUTH PLATTE RIVER BASIN PROJECT
U.S. Public Health Service

Background and Objectives

On July 18, 1963, the Governor of Colorado requested the Secretary of Health, Education, and Welfare to assist the State in determining sources of pollution and quality of waters of the South Platte River Basin within the State of Colorado.

The First Session of the Conference in the matter of Pollution of the South Platte River Basin was held in Denver, Colorado, on October 29, 1963, under the provisions of the Federal Water Pollution Control Act as amended (33 U.S.C. 466g). It was established at this Conference that a study would be undertaken by facilities of the U.S. Public Health Service. Findings and recommendations from this study would lead to a program of pollution abatement to be developed jointly by the South Platte River Basin Project, Public Health Service, and the Colorado State Department of Public Health.

The long-range goals and objectives of the Project are as follows:

1. Determine the legitimate water uses and locate the sources of pollution having an adverse effect on those uses.
2. Through field investigations determine the physical, chemical, and biological responses of the River to pollution and evaluate the previously located sources of pollution with respect to the conditions in the River.
3. Compute the waste load reductions necessary to obtain desired water quality and recommend water quality control measures needed to effect the desired waste load reductions.

Organization

The South Platte River Basin Project consists of engineering and associated professional and clerical personnel. The Project Headquarters offices are located in downtown Denver and the Laboratory has been established at the Colorado State Department of Public Health, Denver, Colorado. The Project is administratively attached to the Water Supply and Pollution Control program of the Public Health Service, U.S. Department of Health, Education, and Welfare, Region VIII, Denver, Colorado.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the following agencies and groups for the assistance and cooperation which made this report possible.

Colorado State Department of Public Health
Denver, Colorado

Colorado State Engineers Office
Denver, Colorado

Tri-County Health Department
Commerce City, Colorado

Farmers Reservoir and Irrigation Company
Denver, Colorado

Barr Lake Hunting Club
Denver, Colorado

INTRODUCTION

The South Platte River and its tributaries in the vicinity of Denver, Colorado, are principal sources of water supply for the area. They are also the receptacle for used water. Water is used and reused for domestic and industrial water supply and for irrigation. Established water rights regulate the amount of withdrawal and period of withdrawal for the water in the River system. As the population of the area has grown over the years, the competition for this water has intensified along with the necessity for increased reuse. To help in meeting the need for water reuse, the City of Denver constructed a sewage treatment plant and placed it in operation in 1937 (1). Since then, other communities have constructed sewage treatment plants discharging to the South Platte River system. Additional domestic and industrial waste water treatment facilities are needed. There is also a need for the connection of numerous domestic and industrial discharges into existing sewer systems.

Water is diverted from the South Platte River into the Burlington-O'Brian Canal immediately downstream from the Denver North Side sewage treatment plant as shown in Figure 1. This canal is used by the Farmers Reservoir and Irrigation Company for storing irrigation water in Barr Lake through diversion of South Platte River water chiefly during the non-irrigation season. It is also used to supply the Denver-Hudson Canal and the Burlington Ditch. Water of similar quality is diverted by others from the South Platte River into the nearby Fulton Ditch and the Brantner Ditch.

Over the years, numerous complaints of odors have been received from Brighton and vicinity (2), a city of some 10,000 persons, located about 2.7 miles northwest of Barr Lake. These odors have been attributed to Barr Lake (1) (2) (3) (4) (5) and the organic loading imposed on this Lake through incomplete treatment of Denver's sewage.

Several studies have been made on this situation, including a Public Health Service investigation in 1948-50, a Colorado State Health Department report (1) in 1956, and the study of Professor Ross E. McKinney (3) in 1963. On October 29, 1963, the South Platte River Basin Project (2) was initiated following an Enforcement Conference held by the Department of Health, Education and Welfare, Public Health Service, at the request of the Governor of Colorado under the provisions of the Federal Water Pollution Control Act as amended (33 U.S.C. 466g). During 1964, Brighton (2) began formal action against several municipalities for their alleged pollution of the South Platte River in the vicinity of Denver. This action was dismissed in court on the grounds that Denver was making satisfactory progress to correct the situation through formation of a sewage disposal district.

During the period of 1960-63, the Metropolitan Denver Sewage Disposal District No. 1 was formed to cope with the sewerage problems of the area. This District commenced construction of secondary sewage treatment facilities in August of 1964, locating the new plant (Figure 2) downstream of the Burlington-O'Brian Canal. Effluent is to be pumped back to the canal as necessary to meet "water right" flow agreements. These additional treatment facilities are not expected to have any immediate influence on the existing South Platte River water quality above the point of effluent discharge from the Denver North Side treatment plant. Numerous domestic and industrial waste discharges must be connected into existing sewer systems.

This study was based on data developed by the South Platte River Basin Project and others as referenced. The purpose of this study was to:

1. Evaluate the present conditions in Barr Lake.
2. Determine the probable conditions to be expected in Barr Lake after completion of the new Metropolitan Denver Sewage Disposal District No. 1 treatment facilities and the approximate length of time required for the Lake to reach these conditions.
3. Recommend measures that might be used for correcting the probable future water quality conditions in Barr Lake should the conditions continue unfavorable after completion of MDSDD#1 treatment facilities.
4. Recommend measures that might be used for improving Barr Lake water quality prior to completion of the MDSDD#1 facility.

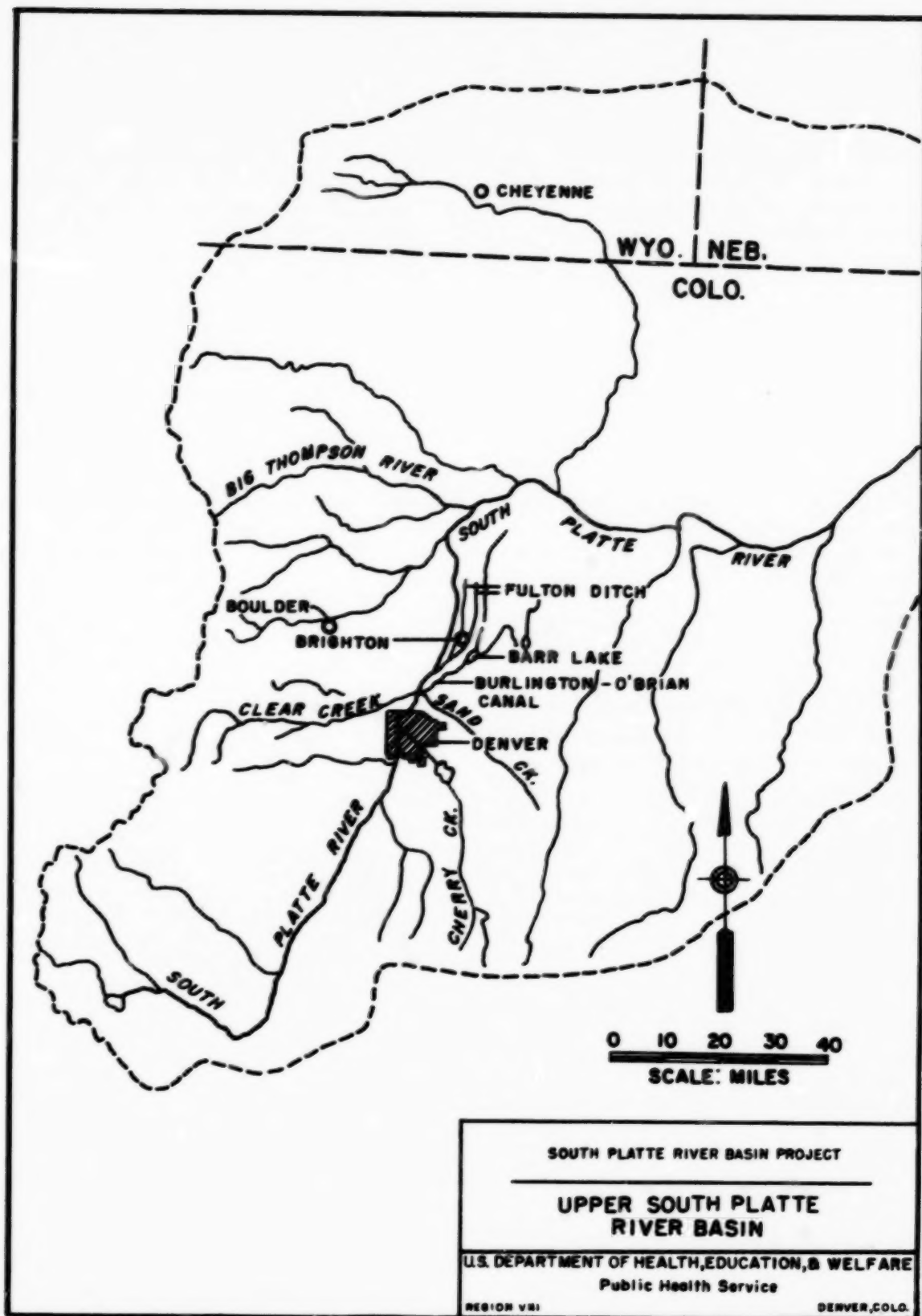


FIGURE-1

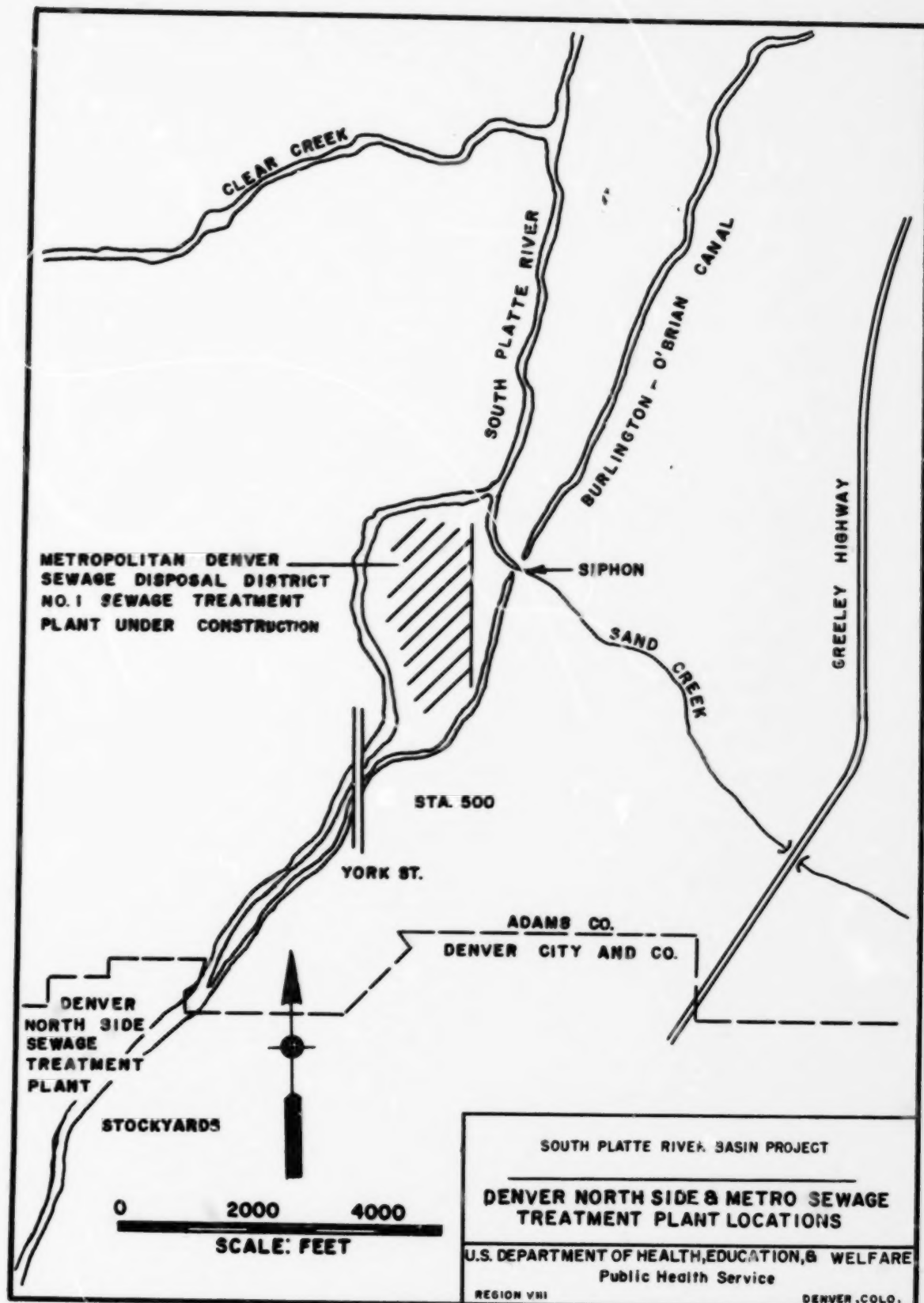


FIGURE-2

BASIC DATA

Characteristics of the study area, the South Platte River, Burlington-O'Brian Canal, Barr Lake, and the sewage treatment facilities are presented in the following pages. Since River flows, temperatures, etc. vary so widely from year to year, monthly means for the past ten years are included in the data for comparative purposes. Water quality data obtained by the South Platte River Basin Project are presented and discussed in a later chapter of this report.

Climatological

Table I lists the yearly normal and study period precipitation and temperatures by the month at the Denver Airport. Also shown is the mean 1961-64 evaporation at Wiggins. The normal annual precipitation is 14.81 inches with about 70 percent of this occurring in the spring and summer. April, May, October and November have relatively warm days and cold evenings. The average evaporation, as measured in the non-freezing period from April to October of 1961-64, was 56.4 inches. Actual evaporation of course exceeds this by several inches due to sublimation of ice and snow and from liquid surfaces during portions of March and November. The study period from March of 1964 to March of 1965 was drier than normal, although temperatures were about normal.

The U.S. Weather Bureau has recorded a mean yearly wind direction in the Denver-Brighton area as shown below, during the period of 1931 to 1960, having a mean monthly velocity of 8-11 mph.

South	30%	North	8%
Southwest	20%	East	8%
Southeast	10%	Northwest	7%
Northeast	10%	West	7%

This prevailing southerly wind usually develops in the area after dark unless the local weather is being dominated by a particular storm system. The mean monthly wind velocities during the study period were as shown below. Wind directions followed the pattern above.

March, 1964	8.8 mph	October, 1964	7.1 mph
April, 1964	9.5 mph	November, 1964	8.2 mph
May, 1964	8.6 mph	December, 1964	9.2 mph
June, 1964	7.8 mph	January, 1965	9.0 mph
July, 1964	7.0 mph	February, 1965	8.7 mph
August, 1964	8.8 mph	March, 1965	7.3 mph
September, 1964	7.6 mph	April, 1965	9.5 mph

TABLE I

Climatological Data¹

Month	Mean Annual ²		1963 Mean		1964 Mean		1965 Mean		Evaporation
	Precip. In.	Temp. °F	Precip. In.	Temp. °F	Precip. In.	Temp. °F	Precip. In.	Temp. °F	Inches
January	0.55	28.5	0.71	19.1	0.26	30.6	1.00	35.0	-
February	0.69	31.5	0.21	37.3	1.04	27.4	1.27	27.4	-
March	1.21	36.4	1.42	37.3	1.38	33.0	1.20	29.0	-
April	2.11	46.4	0.03	50.0	1.25	46.6			7.6
May	2.70	56.2	0.68	60.9	2.53	58.8			9.6
June	1.44	66.5	3.59	66.7	0.82	65.0			9.5
July	1.53	72.9	0.55	74.8	0.72	75.8			11.1
August	1.28	71.5	2.52	68.7	0.27	70.4			7.9
September	1.13	63.0	1.25	65.9	0.41	62.5			6.1
October	1.01	51.4	0.31	57.9	0.18	52.7			4.6
November	0.69	37.7	0.45	41.7	0.88	40.0			-
December	0.47	31.6	0.51	28.5	0.40	33.2			-
	14.81	49.5	12.23	50.8	10.14	49.7			56.4

¹ U.S. Weather Bureau, Denver Airport, except evaporation which is the 1961-64 mean for Wiggins, Colorado.

² Period of record, 30 years to 1964.

Flow Data, South Platte River

In Table II is given the 10-year mean monthly discharge of the South Platte River above the Denver North Side sewage treatment plant; the sewage treatment plant discharge; the diversion into the Burlington-O'Brian Canal; the percent of River flow diverted into the Burlington-O'Brian Canal; and the percent of River flow that consists of Denver sewage plant effluent. River flow is normally greatest in the period of April through August. The sewage treatment plant discharge has averaged about 93 CFS (60 MGD) during the past 10 years but has now increased to a present mean of about 110 CFS. Below the point of Denver's treatment plant discharge, the percent of flow in the River representing the Denver North Side treatment plant effluent has ranged from a high of 58 percent in January to a low of 13 percent in May. This effluent has averaged 35 percent of the River flow for the entire year, which is a significant percentage. Because of upstream effluent discharges, the percent of used water in the South Platte River is considerably higher than indicated on Table II. The quantity of water diverted into the Burlington-O'Brian Canal for Barr Lake storage is greatest in the non-irrigation months of October-March. Diversion in the other months is usually for direct application. The largest percentage of River flow is also diverted in the non-irrigation months of October through March, a period when the normal River flow is the least. This has averaged over 80 percent in December and January.

Table III lists the actual monthly flow values during the period of study. During this period, South Platte River flows were significantly less than the 10-year norm (Table II) in every month.

Burlington-O'Brian Canal

The South Platte River is diverted into the Burlington-O'Brian Canal about one-quarter mile below the Denver North Side sewage treatment plant outfall at the north Denver City and County limits (see Figure 2). In some years when River flow is down, water is not diverted during a portion of the spring and summer. A decree was granted the Farmers Reservoir and Irrigation Co. in 1957 permitting them to divert additional water providing it was put to direct use and not stored in Barr Lake. Diversion for Barr Lake storage is normally during the non-irrigation months.

The Canal is 17.2 miles long to Barr Lake and has a flow time that is estimated to vary between 12 and 17 hours, depending upon the rate of flow. In addition to supplying water for Barr Lake, the Canal carries water for the Denver-Hudson Canal and the Burlington Ditch. The water in Burlington Ditch is distributed for direct use while that in the Denver-Hudson Canal is used to fill other irrigation storage reservoirs north and east of Brighton as well as for direct use.

Canal diversions from the South Platte River during the study period were greater than the 10-year norm in the months of March and April, the same in December, and less in the other months.

TABLE II

Discharge and Diversion Data; 10-Year Mean;
Cubic Feet per Second (CFS)

Month	South Platte River Above Denver STP ¹	Denver STP ²	Percent Flow from Denver STP	Burlington- O'Brian Canal Diversion ³	Percent River Flow Diverted
January	70	95	58	137	83
February	84	81	49	106	65
March	140	89	39	127	55
April	265	87	25	135	38
May	635	96	13	129	18
June	432	84	16	170	33
July	304	103	25	85	21
August	325	104	24	73	17
September	157	98	38	67	26
October	131	97	43	118	52
November	128	90	41	156	71
December	93	<u>91</u> 93	49	151	<u>82</u> 47

¹ U.S.G.S. data; Oct. 1953 - Sept. 1963; 19th St. Bridge

² Denver North Side Sewage Treatment Plant Records, 1954-63

³ Burlington Ditch Reservoir and Land Co. Records, Jan. 1954 - Dec. 1963

TABLE III
Mean Monthly Flow Data for Study Period
(Values in CFS)

Month	South ¹ Platte River	Denver North Side STP	Burlington- O'Brian Canal Diversion	Percent South Platte R. Flow Diverted	Barr Lake Inlet	Barr Lake Outlet	Barr Lake Contents AC-FT	Barr Lake Surface Area Acres
Mar. 1964	90	102	187	97	77	0	21,770	1550
Apr.	177	103	271	97	143	10	28,358	1790
May	314	100	49	12	4	119	19,172	1450
June	188	102	110	38	22	17	18,397	1400
July	169	129	34	11	0	155	6,279	720
Aug.	235	122	28	8	0	71	857	315
Sept.	60	101	27	17	0	7	0	0
Oct.	41	117	35	22	8	5	320	245
Nov.	70	112	89	49	18	0	730	300
Dec.	51	109	150	94	125	0	7,869	825
Jan. 1965	51	104	104	67	74	0	12,208	1090
Feb.	54	99	34	22	0	0	11,504	1065
Mar.	70	<u>122</u>	73	<u>38</u>	31	0	12,958	1135
		109		44				

¹ Above Denver North Side Sewage Treatment Plant

Barr Lake

Barr Lake is essentially an artificial impoundment that is filled by diversion from the South Platte River principally during the non-irrigation season. It normally discharges during the period of May through September into the Speer Canal, east and west Burlington Extension Ditches, Beebe Seep Canal, and Neres Canal. Barr Lake is located about 2.7 miles southeast of Brighton and 14 miles northeast of Denver.

Physical characteristics of the Lake are:

1. Volume, full pool, 33,011 acre-feet: 32,152 acre-feet usable
2. Surface area, full pool: 1870 acres, or 2.92 square miles
3. Full pool elevation, 5094 feet
4. Dead pool elevation, 5060 feet
5. Maximum depth, full pool, 42 feet

Table IV shows the average inflow and outflow from Barr Lake during the past 10 years. In an average year, the Lake is not filled prior to the irrigation season nor is it empty at the end of the irrigation season. In 1964 it was empty before the end of the irrigation season. In March of 1965, the Lake contained only 60 percent of its normal volume. The mean yearly total inflow has been 35,537 ac-ft. while the outflow (Table IV) has been 23,978 ac-ft. As the mean evaporation would total about 6,000 ac-ft., it is evident that seepage losses from the Lake are significant.

Existing Denver North Side Sewage Treatment Plant

The existing Denver North Side sewage treatment plant was placed in operation in 1937 to serve a population of about 240,000 persons together with industrial effluent (1). Chemical coagulation, sedimentation, filtration through magnetite filters, and separate sludge digestion were provided in the original construction. Shortly after the plant went into operation, the chemical coagulation and magnetite filter processes were discontinued because of cost and operating problems. In later years, pre-aeration and additional facilities for conventional primary treatment (plain sedimentation) were added. The effluent is intermittently chlorinated and passes through a chlorine contact tank. Sludge digestion and hydraulic capacities are overloaded at times resulting in sludge discharge to the River and by-passing of the treatment plant.

It is estimated that the present total population equivalent (on a biochemical oxygen demand basis) connected to the treatment plant is 1,020,000 persons.¹

¹ SPRB Project estimate based on average BOD values.

TABLE IV

Barr Lake Water Budget Data¹ Mean Monthly Values
Nov. 1953 to End Oct. 1963

Month	Inflow		Outflow		Contents AC-FT ²	Reservoir		
	AC-FT	CFS	AC-FT	CFS		Surface Elev.	Area Acres	Mean Depth ⁷
Jan.	4574	77	-	-	17,506	5085	1350	13
Feb.	3471	58	-	-	20,092	5086.5	1445	14
Mar.	2589	43	-	-	21,709	5088	1552	14
Apr.	3242 ⁴	54 ⁴	513 ⁵	8 ⁵	23,380	5089	1616	14.5
May	3266 ⁴	55	4359	69	20,879	5087	1478	14
June	3641 ⁴	61 ⁴	5271	89	17,901	5085	1350	13
July	985 ³	17 ³	6069	102	11,026	5079.5	1030	11
Aug.	848 ⁶	14 ⁶	5394	90	5,061	5072.5	645	8
Sept.	1035 ⁵	17 ⁵	1934	33	3,614	5070	550	7
Oct.	3182 ⁴	53 ⁴	424 ⁴	7 ⁴	6,119	5074	717	9
Nov.	4186 ⁴	70 ⁴	14 ³	-	9,831	5078.5	960	10
Dec.	4518	76	-	-	13,547	5082	1156	12

¹ Calculated from Irrigation Co. data obtained by PHS

² Last day of month

³ One year of flow only

⁴ No flow in some years

⁵ Three years of flow only

⁶ Five years of flow only

⁷ Volume divided by surface area. Reservoir has been completely emptied by Sept., Oct., or Nov. three times in past 10 years.

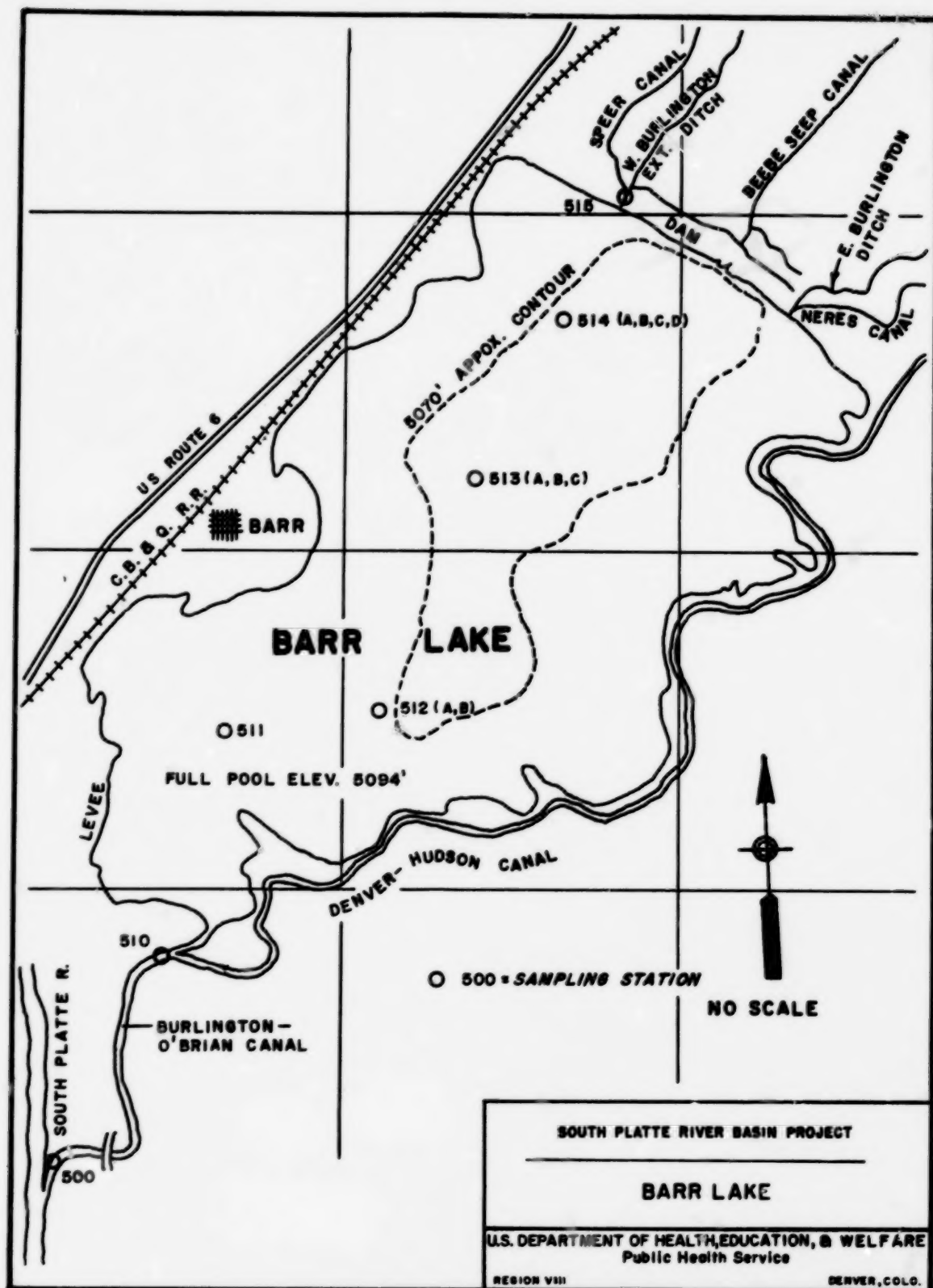
Metropolitan Denver Sewage Disposal District No. 1 Plant

In August of 1964, MDSDD #1 commenced construction on secondary (biological) sewage treatment facilities that are scheduled to be completed in late 1966 or early 1967. The new plant is located about one and one-half miles downstream from the existing Denver North Side plant and thus will be below the Burlington-O'Brian Canal diversion point. In February of 1965 two irrigation companies and an irrigation district filed a \$25 million civil suit (5) in the District Court at Brighton, charging that the new sewage treatment plant being built in Adams County by the Metropolitan Denver Sewage Disposal District will deprive Adams and Weld County farmers of at least 50,000 acre-feet of irrigation water annually. It is anticipated that plant effluent will be pumped back into the Canal as necessary to satisfy existing water rights.

The MDSDD #1 plant will provide activated sludge treatment by either the step or conventional aeration processes, involving a detention period of about four hours at the design average flow of 117 MGD, allowing for 25 percent return sludge. The Denver North Side primary treatment plant will continue to operate and its effluent will be pumped to the new plant and metered directly into the aeration units. Raw sewage from the Sand and Clear Creek drainage basins will pass through screens and a grit and grease removal unit of the aerated type, prior to entering the new primary sedimentation basins. Activated sludge aeration basin effluent will pass through secondary settling basins and then a chlorine contact chamber. From the chlorine contact chamber, the plant effluent will pass into the South Platte River or be pumped as necessitated by water right agreements to the Burlington-O'Brian Canal.

Digested sludge from the Denver North Side plant will be pumped to the Metro plant for disposal with Metro sludge. Metro primary sedimentation sludge is to be combined with the waste activated sludge (concentrated by air flotation) for chemical coagulation and dewatering on vacuum filters. Incineration or flash drying will be used for the final disposal of all sludges.

The consulting engineer's design criteria (6) do not indicate how much plant capacity is reserved for future organic load increases.



THE PROBLEM

The South Platte River is polluted by municipal and industrial wastes in the vicinity of Denver and pollution is particularly severe during periods of low stream flow. A major portion of this pollution originates at the Denver North Side sewage treatment plant which provides only primary sewage treatment and has facilities which are frequently overloaded. An attempt by Adams County to force the Colorado Health Department to take court action against five metropolitan communities for polluting the South Platte River was rejected in a Denver district court on June 3, 1965 (5).

There are essentially three problems; one is the present polluted condition of the South Platte River; another is the use of this River water for irrigation and stock watering; and the other is the presence of disagreeable seasonal odors which have been attributed to Barr Lake and its contents of South Platte River water. This study is concerned only with an analysis of the odor problem.

Until the Public Health Service started the South Platte River Basin Project water quality studies in March of 1964, there had been only random samplings of the treatment plant effluent, the River and the Lake. The odor problems in Brighton have been blamed on Barr Lake (5) with little substantiating or documentary evidence that they all or partially originated in Barr Lake, other than some limited observations by Mr. R.E. Sandersfeld, the former Brighton City Engineer (4).

Barr Lake Odors

Odors observed in Brighton may originate from a number of possible sources, including Barr Lake. These would include the Gates-Cyclo poultry waste lagoon, a number of feed lots, several industries, the Burlington, the Fulton and the Brantner ditches, and the Skeel Reservoirs. Odors emanating from the ditches or reservoirs would be caused by the same source as odors from Barr Lake.

The prevailing wind direction is from the south and southwest as measured by the Weather Bureau at Stapleton Field. This would place Brighton somewhat downwind from Barr Lake.

Mr. Sandersfeld, former City Engineer of Brighton, describes² (4) the odors attributed to Barr Lake as resembling that of hydrogen sulfide.

¹ By other than the City of Denver

² Mr. Sandersfeld made these observations from the autumn of 1962 into the spring of 1964. Odors were not reported in the autumn of 1964 but were observed near the Lake in the spring of 1965. As shown in Tables III and V, the organic loading imposed on Barr Lake in October and November of 1964 was relatively small.

He stated that they were quite noticeable in the months of March to late May and from late October to late November, beginning quite consistently about 7:00 pm and ending about 11:00 pm. This, as suggested by Mr. Sandersfeld, can be due to a temperature inversion in the evening. The days are sunny and reasonably warm, creating a rapid temperature lapse with distance above the ground. This condition would permit any odors from Barr Lake to rise and be widely dissipated. After or near sundown, the ground temperature drops rapidly while the air still remains relatively warm, creating a temperature inversion near the ground. This prevents any odors from rising and dissipating through dilution. A southerly wind could then carry the concentrated odors a considerable distance before they would become diluted and undetected. The temperature inversion would be dispelled later in the evening through natural cooling of the air.

The South Platte River contains a relatively large amount (compared to most other U.S. rivers) of sulfates. These sulfates are reduced to other compounds such as sulfides, which are odorous, under prolonged anaerobic conditions. Barr Lake is probably in an anaerobic state during the winter and a portion of the spring and autumn of each year under present conditions. The greater the sulfate content of the water, the more sulfur there is available for odorous compounds.

PRESSENT CONDITION OF BARR LAKE

As discussed in a previous section, Barr Lake is supplied with water from the South Platte River through the Burlington-O'Brian Canal. There is an inadequacy of data on which to base a rigorous calculation of the organic pollution load imposed on Barr Lake. Data do exist however for generalized observations on probable mean conditions. A plot of South Platte River flow rates with the limited available observations on River BOD values both above and below the Denver North Side Sewage Treatment Plant does not show good correlation between flow rates and BOD values. Factors other than dilution are involved in the River BOD above the treatment plant; factors such as seasonal industrial activity, flushing of storm sewers, and sewer overflows. A study of River BOD data available indicates that a mean yearly value of 15 mg/l (5-day, 20°C) would be a reasonable one to use for approximate calculations.

Adequate flow data on the River and the Denver North Side plant effluent are available as well as on the plant effluent BOD.

Biochemical Oxygen Demand Loading

Table V gives the estimated probable biochemical oxygen demand loadings on Barr Lake during the study period. BOD values in the Burlington-O'Brian Canal were calculated using mean monthly River and Denver North Side treatment plant flow values (Table III) together with an upstream River BOD value approximated at 15 mg/l as discussed in the previous section. These values tend to be low, or conservative, when compared with some of the BOD values that have been collected. They are intended to represent mean and not extreme conditions. Table V shows that the maximum BOD loadings occurred in the months of October to March when the Lake was least able to assimilate the organic loading. No BOD reduction was assumed in the Canal because the reduction is small and because of the intermittent discharge of sludge into the River that is not reflected in treatment plant effluent BOD values. The possible significance of the BOD loadings on Barr Lake is discussed in a later portion of this section.

Table VI for comparison gives the estimated probable BOD loadings on Barr Lake during the 10-year period represented in Table II. River BOD values above the treatment plant were taken at 15 mg/l as before and treatment plant effluent BOD values averaging 175 mg/l as reported in references (1) (2) and (3). Table VI indicates that the BOD loadings on Barr Lake during the study period (Table V) were alternately relatively light and heavy compared with the means of Table VI. During the study period (March 1964 to March 1965) there was no loading in the summer and heavier than usual loadings in the spring and winter, although none in February of 1965.

Table VI indicates that maximum BOD loadings occur in the colder months when the Lake is least able to assimilate them.

TABLE V

Biochemical Oxygen Demand¹ Loadings on Barr Lake
(Estimated Mean Monthly in Study Period)

Month	Mean S. Platte River Flow CFS ²	Mean Denver North Side STP Flow CFS ³	Mean Denver North Side STP BOD mg/l ³	Combined BOD in River Be- low STP mg/l ⁴	Barr Lake Inflow CFS ⁵	BOD Loading Barr Lake Thous lbs /Day	BOD Loading Barr Lake lbs/Acre/ Day
Mar. 1964	90	102	119	70	77	29	18.7
Apr.	177	103	175	73	143	56	31.4
May	314	100	173	53	4	1.1	0.8
June	188	102	155	64	22	7.6	5.4
July	169	129	154	75	0	0	0
Aug.	235	122	139	58	0	0	0
Sept.	60	101	173	115	0	0	0
Oct.	41	117	184	140	8	6	24.6
Nov.	70	112	165	107	18	10	34.5
Dec.	51	109	179	127	125	85	103.0
Jan. 1965	51	104	174	122	74	48	44.3
Feb.	54	99	163	111	0	0	0
Mar.	70	122	198	131	31	22	19.2

¹ 5-day 20°C values

² Gaged flow above Denver North Side Sewage Treatment Plant

³ From Denver North Side STP records

⁴ Using a mean BOD in the South Platte River estimated at 15 mg/l

⁵ From Table III

TABLE VI

Biochemical Oxygen Demand Loading on Barr Lake
(Estimated Mean Monthly in Period 1953-1963)

Month	South Platte R. Above Denver CFS	STP ¹	Denver STP ¹ CFS	Combined BOD in River Be- low STP ² mg/l	Barr Lake Inflow CFS ³	BOD Loading Barr Lake Thous lbs /Day	BOD Loading Barr Lake lbs/Acre/ Day
Jan.	70		95	107	77	44.4	32.8
Feb.	84		81	94	58	29.3	20.3
Mar.	140		89	78	43	18.0	11.6
Apr.	265		87	55	54	16.0	9.9
May	635		96	36	55	10.6	7.2
June	432		84	41	61	13.5	10.0
July	304		103	55	17	5.0	4.9
Aug.	325		104	54	14	4.1	6.4
Sept.	157		98	77	17	7.0	12.7
Oct.	131		97	84	53	23.8	33.3
Nov.	128		90	81	70	30.5	31.8
Dec.	93		91	94	76	38.4	33.2

1 Data from Table II

2 Using River BOD of 15 mg/l and STP effluent of 175 mg/l

3 From Table IV

Water Quality Data

In March 1964, the South Platte River Basin Project established 13 sampling stations on Barr Lake and adjacent canals, as shown in Figure 3. The stations were sampled at about bi-weekly intervals at all locations except when Lake drawdown, cessation of irrigation flow, or freezing precluded their sampling. Sampling points were selected to show the quality of water diverted to Barr Lake; quality changes that may take place in the diversion canal; change in Lake quality with depth and with position in the Lake; change in quality after passing through the Lake or by traveling an equivalent distance in the Denver-Hudson by-pass canal. Sludge deposits in the Burlington-O'Brian Canal and in the Lake were investigated and sampled. Table VII lists the sampling station locations. Determinations were generally by standard procedures (7).

Tables VIII-XIV present the water quality sampling data at various depths for the sampling period and Table XV shows the mean values of bottom sludge analyses. Data presented in Tables VIII-XV were compiled from field and laboratory observations made by the South Platte River Basin Project, between the period of March, 1964 and May, 1965 (8). Data were not collected routinely because there was no Lake inflow in July, August, September and February; the Lake was empty in August; and the Lake was ice-covered from December to the middle of April, 1965. Water was not diverted into Barr Lake during most of April and May of 1965 because of low-water conditions in the South Platte River and because sewage from the Denver North Side STP was bypassed directly to the River from April 16 to June 3, 1965 to permit construction of plant modifications relative to the new Metro plant. A discussion of this water quality data follows:

General: Nitrate nitrogen, total nitrogen, total phosphate, and soluble phosphate concentrations were determined in samples collected after August of 1964. Data that are missing in the tables either were not collected or the analytical results were not reliable and therefore not reported. The few nitrogen and phosphate samples collected on the Canal and Lake on the same sampling trip indicated a complete reduction of nitrates in the Lake (anaerobic conditions persisted at the time), little change in organic nitrogen, and a phosphate reduction in the Lake of about 75 percent.

The BOD and COD values obtained did not present a uniform relationship other than that COD values were usually two to four times greater than the BOD values. This would be expected however.

Values obtained were from grab samples and thus individual results must be examined collectively since the water being sampled was constantly varying in quality due to changes in flow, treatment plant operations, and variations in the activity of the biota with diurnal changes in temperature and insolation. Samples were collected between 8:30 am

and 7:30 pm, most samples being collected prior to 2:00 pm. The time of day that surface samples are collected from Barr Lake would have a large influence on the presence or absence of dissolved oxygen and the quantity of oxygen obtained, once photosynthesis has been established to a significant degree in the late spring.

Burlington-O'Brian Canal, Station 500, Table VIII: During the period sampled, the Burlington-O'Brian Canal at York Street (just after diversion from the South Platte River) had a variable quality depending upon the rate of River flow for effluent dilution and upon the presence of digester sludge and supernatant in the River (very high suspended solids were observed on several occasions). In general, Table VIII indicates the following:

1. Dissolved oxygen in appreciable amounts was present in the water diverted into the canal at all times of sampling.
2. The diverted water, considering that it came from a surface stream of mountain origin, was high in dissolved solids, alkalinity, and conductivity, indicating the presence of irrigation return flow and ground water seepage.
3. The diverted water had an extremely high (for a river water) biochemical oxygen demand, chemical oxygen demand, and volatile suspended solids content, indicating the presence of a large amount of inadequately or improperly treated sewage. BOD values averaged about 125 mg/l.
4. Coliform bacteria concentrations were relatively low when effluent disinfection was practiced and high when not. They were normally unusually high for any stream in an urban area.
5. Plant nutrients, in abnormally large amounts for a surface stream, were being diverted into Barr Lake.
6. pH values were normal but the content of synthetic detergents expressed as ABS was very high for a surface water.

Barr Lake Inlet, Station 510, Table IX: During the 17 miles of flow in the canal to Barr Lake, the following water quality changes occurred:

1. The dissolved oxygen was found to be entirely consumed in all samples taken.
2. The pH was usually somewhat depressed due to the formation of amino acids and carbonic acid.
3. Some of the suspended solids were deposited on the canal bottom but this is not reflected in the sample values.

4. An aftergrowth of coliform bacteria was frequently observed, Barr Lake Inlet concentrations exceeding those at York St.
5. Most of the nitrates were reduced to nitrites or ammonia.
6. A slight decrease in the mean BOD from 125 to 115 mg/l.

Other constituent values were not changed appreciably over those found in the water as diverted.

Barr Lake, Tables X-XIII: Mean values are shown in Tables X-XIII for the four Lake stations. As the Lake was drawn down during the summer, these four stations were gradually dewatered until only station 514 remained at the end of August 1964. Self-purification in the Lake was very slow until the water warmed to about 15°C in the latter part of May 1964. This warming due to the added insolation produced increased bacterial and phytoplankton activity. The quality of water being introduced to the Lake also improved because of the increased flow in the South Platte River, Table III. In the latter part of May, photosynthetic production of oxygen exceeded the biochemical oxygen demand during daylight hours and dissolved oxygen was then found in the upper waters of the Lake during the remainder of the summer sampling periods.

This dissolved oxygen probably did not persist in the upper waters throughout the night in May and perhaps into June because of the high BOD in the water and the lack of much dissolved oxygen in the deeper waters. Self-purification, with a reduction in BOD, was so rapid after the middle of June that dissolved oxygen probably persisted in the surface water throughout the night. Dissolved oxygen was found at the 20 and 30 foot depths only during June, perhaps because of unusual wind mixing and heavy algal activity at that time.

Other than a small temperature difference, the only apparent changes in water quality with depth in Barr Lake were caused by the phytoplankton, which produced some variations in pH, suspended solids and dissolved oxygen between the deeper and the surface waters. Total suspended and volatile suspended solids were usually about equal at all depths, indicating the high organic content of the suspended matter.

By the end of June 1964, self-purification had reduced the BOD of Barr Lake to a relatively low value and the coliform bacteria concentrations were similar to or lower than those normal to surface waters in a farming region. Other constituents were little changed in their passing through Barr Lake.

Anaerobic conditions persisted in Barr Lake into May of 1964 and were probably present again in October or November and beyond when quantities of sewage-laden water were diverted into the Lake and phytoplankton activity was reduced. Under usual present conditions, odors

could be emitted therefore from Barr Lake after the ice melts until usually about the end of May, commencing again about October or November and lasting until the Lake freezes.

Self-purification was more evident in Barr Lake in the spring of 1965 (April and May samples, Table X) because water had not been introduced to the Lake since April 16. Dissolved oxygen was not present in the Lake by May 6, 1965 however and the Lake had a pronounced odor of hydrogen sulfide in the immediate vicinity but no complaints were received from the Brighton area.

Plankton: Plankton samples were collected in Barr Lake periodically from April through August of 1964 and examined at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio (8). These analyses may be summarized as follows:

1. Algae and other organisms that predominated were of the type usually associated with organically polluted waters.
2. Numbers of algae were lowest in early spring (about 10,000 per ml) when water temperatures were low and were maximum in May (about 800,000 per ml) when water temperatures had risen, solar radiation increased, and the food source was maximum. During June, July, and August, the number of algal organisms fluctuated between 15 and 45 thousand cells per milliliter.
3. The numbers of algae present in the surface waters of Barr Lake during all periods of observation (April 23 to August 6, 1964) were in sufficient quantity to be defined as a "nuisance" bloom, had the water been used for any purposes but irrigation.
4. Blue-green algae predominated in April and May while green algae were dominant in June, July, and August.
5. The ability of Barr Lake to support this large algal mass is due to the heavy fertilization the Lake receives from waste water discharges.

Bottom Organisms: Bottom organisms were non-existent in Lake areas having no dissolved oxygen. Bloodworms (midge larvae hatched from eggs deposited by adult flying midges from other water bodies) became established in the shallower portions of the Lake when dissolved oxygen became available in the late spring. Other bottom organisms such as leeches, snails and sludgeworms that are usually found in organically rich bottom deposits were not found in Barr Lake. Mosquito larvae were observed in the surface waters near shore where vegetation provided some protection. The midge pupae, being less tolerant than the larvae, were found in the areas where the water depth was three feet or less.

TABLE VII

Sampling Station Locations (See Figure 3)

<u>Station No.</u>	<u>Location</u>
500	Burlington-O'Brian Canal at York St. Bridge
510	Barr Lake Inlet at Denver-Hudson Canal diversion
511	Barr Lake, 1/4 point, 1-ft. depth
512A	Barr Lake, 1/2 point, 1-ft. depth
512B	Barr Lake, 1/2 point, 5-10 ft. depth
513A	Barr Lake, 3/4 point, 1-ft. depth
513B	Barr Lake, 3/4 point, 10-ft. depth
513C	Barr Lake, 3/4 point, 20-ft. depth
514A	Barr Lake, 4/4 point, 1-ft. depth
514B	Barr Lake, 4/4 point, 10-ft. depth
514C	Barr Lake, 4/4 point, 20-ft. depth
514D	Barr Lake, 4/4 point, 30-ft. depth
515	Outlet canal for Barr Lake

TABLE VIII

Burlington-O'Brian Canal at York Street Water Quality
Station 500

Constituent	1964							1965		
	3-19	3-26	4-9	4-23	6-4	12-2	12-22 ¹	1-122	3-29	4-6
Temp., °C	8.0	10.5	12.0	14.5	19.5	13.0	12.0	11.9	11.0	14.0
D.O., mg/l	6.9	6.6	4.8	4.4	4.8	3.1	3.7	3.0	4.6	4.2
pH	8.2	7.4	8.0	7.6	7.7	7.4	7.3	7.3	7.0	7.6
Tot. alk. as CaCO ₃	190	200	225	165	210	-	-	-	-	-
BOD, mg/l	220	55	165	95	80	80	125	250	60	120
COD, mg/l	480	200	300	145	220	160	195	195	-	-
Cond. umhos/cm.	795	1260	1240	830	890	1120	990	1120	1010	1100
Chlorides, mg/l	104	160	132	74	81	101	111	96	120	117
Tot. Diss. Sol., mg/l	490	780	710	515	515	-	-	-	-	-
Susp. Sol., mg/l	2500	88	180	1590	1040	115	125	120	100	125
Vol. Susp. Sol., mg/l	330	50	140	640	650	80	105	110	50	90
Sett. Sol., mg/l	25	0.4	0.7	0.3	0.2	0.1	0.1	0.2	0.2	0.5
NO ₃ N, mg/l	0.20	0.44	0.52	0.66	0.26	0.38	0.28	0.21	0.74	-
Total N, mg/l	-	-	-	-	-	30	16.1	18.4	10.5	17.1
Total PO ₄ , mg/l	-	-	-	-	-	9.5	9.15	16.8	9.2	11.2
Sol. PO ₄ , mg/l	-	-	-	-	-	6.3	7.55	16.3	8.0	9.3
ABS, mg/l	0.3	1.4	2.4	2.3	0.9	0.7	-	-	-	-
Coliform/100 ml.	90,000	300	1,800	12,000	54,000	4,900	570,000	29,000,000	490	-

¹ Mean of samples on 12/15, 12/22 and 12/29

² Mean of samples on 1/6, 1/12 and 1/18

TABLE IX

Barr Lake Inlet Water Quality
Station 510

Constituent	1964					1965				
	3-19	3-26	4-9	4-23	6-4	12-2	12-221	1-122	3-29	4-6
Temp., °C	9.0	8.5	13.5	15.0	17.3	9.5	12.1	9.3	10.0	12.0
D.O., mg/l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	7.4	7.4	7.5	7.6	7.4	7.3	7.3	7.4	7.4	7.5
Tot. alk. as CaCO ₃	210	200	215	215	190	-	-	-	-	-
BOD, mg/l	130	115	125	90	55	150	135	135	96	120
COD, mg/l	335	265	260	215	85	200	225	200	-	-
Cond., umhos/cm	895	1420	1050	970	925	1250	1200	1090	965	1010
Chlorides, mg/l	106	206	156	111	84	-	133	108	123	100
Tot. Diss. Sol., mg/l	575	820	830	625	510	-	-	-	-	-
Susp. Sol., mg/l	555	230	1390	1140	290	122	170	155	260	125
Vol. Susp. Sol., mg/l	135	135	520	610	240	79	120	110	120	75
Sett. Sol., ml/l	3.5	1.0	1.2	0.1	0.1-	0.4	0.5	0.4	-	-
NO ₃ N, mg/l	0.19	0.12	0.12	0.07	0.16	0.18	0.15	0.15	0.09	-
Total N, mg/l	-	-	-	-	-	36.8	15.3	18.0	13.8	12.4
Total PO ₄ , mg/l	-	-	-	-	-	10.6	16.1	21.2	12.6	16.0
Sol. PO ₄ , mg/l	-	-	-	-	-	1.1	9.6	17.8	10.0	12.8
ABS, mg/l	2.1	1.8	3.0	2.4	0.8	-	-	-	-	-
Coliform/100 ml.	790,000	1,300,000	49,000	1,300,000	3,500,000	-	6,000,000	7,200,000	28,000	-

¹ Mean of samples on 12/8, 12/15, 12/22 and 12/29² Mean of samples on 1/6, 1/12 and 1/18

TABLE X

Barr Lake Surface Water Quality
Mean of Stations 511-514

Constituent	1964										1965	
	3-26	4-23	5-11	5-20 ¹	6-4	6-18	7-1	7-16	8-6 ³	8-27 ⁴	4-30	5-6
Temp., °C	4.7	13.3	13.3	25.0	16.9	20.5	22.2	27.3	24.5	16.0	16.9	15.0
D.O., mg/l	0.0	0.0	0.0	7.9	0.6	13.0	1.4	2.4	3.6	10.2	0.0	0.0
pH	7.7	7.9	7.7	8.3	7.9	8.7	8.1	8.2	8.2	9.0	7.7	7.9
Total Alk. as CaCO ₃	284	255	265	285	277	270	270	276	283	272	-	-
BOD, mg/l	32	33	21	21	11	13	3.5	8	6	-	25	23
COD, mg/l	105	85	135	160	75	22	8.0	95	47	95	77	79
Cond., umhos/cm	1285	1225	1260	1310	1165	1180	1230	1220	1300	1170	1160	1160
Chlorides, mg/l	143	134	137	135	122	118	119	145	-	-	128	115
Tot. Diss. Sol., mg/l	710	720	665	740	650	670	645	710	695	750	690	660
Susp. Sol., mg/l	30	340	220	475	100	-	65	35	16	60	28	23
Vol. Susp. Sol., mg/l	24	285	225	220	100	-	65	12	13	-	28	23
Sett. Sol., mg/l	0.0	0.1-	0.1-	0.5	0.1-	0.1-	0.1-	0.1-	0.1	0.2	0.1-	0.1-
NO ₃ N, mg/l	0.20	0.12	0.14	0.13	0.31	0.12	0.15	0.10	0.40	0.15	0.0	0.0
Total N, mg/l	-	-	-	-	-	-	-	-	-	-	16.4	16.6
Total PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	-	3.3	3.4
Sol. PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	-	3.1	3.3
ABS, mg/l	1.8	2.7	2.7	2.6	1.9	2.0	1.8	2.1	2.7	-	2.2	3.1
Coliform/100 ml	30,000	81,000	32,000	42	2300	4100	5	102	660	330	5900	1100

1 First readily noticeable algae

2 Station 511 has 2200 coliform

3 Stations 513 and 514 only

4 Station 514 only

TABLE XI
Barr Lake Water Quality, 10-Foot Depth
Mean of Stations 512-514

Constituent	1964							1965		
	3-26	4-23	5-11	5-20	6-4	6-18	7-1	7-16	8-6	4-29 5-6
Temp., °C	4.6	12.0	12.0	18.0	16.0	20.0	21.5	24.0	24.0	12.9 14.0
D.O., mg/l	0.0	0.0	0.0	0.2	0.4	12.4	1.2	0.2	1.7	0.0 0.0
pH	7.7	7.9	7.8	8.0	8.0	8.7	8.0	-	-	7.8 7.9
Total alk. as CaCO ₃	300	280	290	280	272	268	276	-	-	- -
BOD, mg/l	40	26	14	15	11	12	8	4	8	28 24
COD, mg/l	86	176	127	176	50	96	38	-	-	65 80
Cond., umhos/cm	1230	1235	1265	1320	1095	1155	1245	-	-	1125 1210
Chlorides, mg/l	142	134	137	136	120	113	-	-	-	115 116
Tot. Diss. Sol., mg/l	730	725	655	682	657	650	675	-	-	700 655
Susp. Sol., mg/l	26	280	12	140	150	35	9	-	-	30 22
Vol. Susp. Sol., mg/l	26	240	12	140	150	28	9	-	-	30 22
Sett. Sol., mg/l	0.0	0.1-	0.1-	0.1-	0.1-	0.1-	0.1-	-	-	0.1 0.1-
NO ₃ -N, mg/l	0.13	0.09	0.09	0.14	0.30	0.08	0.10	-	-	0.0 0.0
Total N, mg/l	-	-	-	-	-	-	-	-	-	16.2 -
Total PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	3.4 3.4
Sol. PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	3.3 3.4
ABS, mg/l	2.1	2.9	2.7	2.7	2.0	1.8	2.1	-	-	1.8 2.8

TABLE XII

Barr Lake Water Quality, 20-Foot Depth
Mean of Stations 513 and 514

Constituent	1964										1965		
	3-26	4-23	5-11	5-20	6-4	6-18	7-1	7-16 ¹	8-6 ¹	4-29	5-6		
Temp., °C	4.5	12.0	12.3	15.8	16.8	20.0	20.7	22.0	23.5	13.0	14.0		
D.O., mg/l	0.0	0.0	0.0	0.0	0.2	11.5	1.0	0.0	0.0	0.0	0.0		
pH	-	-	-	-	-	-	-	-	-	7.8	8.0		
Total alk. as CaCO ₃	-	-	-	-	-	-	-	-	-	-	-		
BOD, mg/l	40	27	14	14	12	6	5	3	10+	26	22		
COD, mg/l	-	-	-	-	-	-	-	-	-	80	-		
Cond., umhos/cm	-	-	-	-	-	-	-	-	-	1150	1240		
Chlorides, mg/l	-	-	-	-	-	-	-	-	-	120	-		
Tot. Diss. Sol., mg/l	-	-	-	-	-	-	-	-	-	690	-		
Susp. Sol., mg/l	-	-	-	-	-	-	-	-	-	21	-		
Vol. Susp. Sol., mg/l	-	-	-	-	-	-	-	-	-	20	-		
Sett. Sol., mg/l	0.0	-	-	-	-	-	-	-	-	0.1-	-		
NO ₃ -N, mg/l	-	-	-	-	-	-	-	-	-	0.0	-		
Total N, mg/l	-	-	-	-	-	-	-	-	-	16.4	-		
Total PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	3.3	-		
Sol. PO ₄ , mg/l	-	-	-	-	-	-	-	-	-	3.0	-		

¹ Station 514 only

TABLE XIII

Barr Lake Water Quality, 30-Foot Depth
Station 514

Constituent	1964					1965	
	4-23	5-11	5-20	6-4	6-18	7-1	4-29
Temp., °C	-	13.0	14.3	16.0	20.0	20.0	13.0
D.O., mg/l	0.0	-	0.0	0.0	13.9	0.0	0.0
pH	7.9	7.8	7.8	8.0	8.4	8.1	7.8
Total alk. as CaCO ₃	292	287	296	286	280	292	-
BOD, mg/l	22	13	16	9	11.0	-	31
COD, mg/l	129	150	121	10	8	0	128
Cond., umhos/cm	1310	1135	1315	1240	1220	1260	1190
Chlorides, mg/l	138	136	134	126	119	-	130
Tot. Diss. Sol., mg/l	785	675	690	650	675	670	700
Susp. Sol., mg/l	32	22	220	130	-	14	190
Vol. Susp. Sol., mg/l	28	200	120	130	-	9	94
Sett. Sol., mg/l	0.1-	-	0.1-	0.1-	0.1-	0.1	2.0
NO ₃ -N, mg/l	0.15-	0.09	0.11	0.38	0.8	0.06	0.0
Total N, mg/l	-	-	-	-	-	-	17.5
Total PO ₄ , mg/l	-	-	-	-	-	-	3.3
Sol. PO ₄ , mg/l	-	-	-	-	-	-	3.2
ABS, mg/l	2.7	2.6	2.5	2.3	2.2	1.7	-
Coliform/100 ml	1100	-	1100	-	-	-	-

TABLE XIV
Barr Lake Outlet Water Quality
Station 515

Constituent	1964					
	5-20	6-4	6-29	7-16	8-6	8-27
Temp., °C	16.3	15.0	20.0	25.0	23.5	18.0
D.O., mg/l	0.3	0.0	3.4	0.8	1.6	8.2
pH	7.9	7.9	8.4	8.4	8.0	9.0
Total alk. as CaCO ₃	316	292	276	268	288	312
BOD, mg/l	13	6	8	4	19	37 ¹
CCD, mg/l	137	14	110	-	51	176
Cond., umhos/cm	1300	1210	1105	1220	1350	1220
Chlorides, mg/l	136	126	131	-	-	-
Tot. Diss. Sol., mg/l	670	-	700	685	710	825
Susp. Sol., mg/l	150	60	32	8	21	150
Vol. Susp. Sol., mg/l	130	60	21	8	15	-
Sett. Sol., mg/l	0.1-	0.1-	0.4	0.1-	0.1-	1.0
NO ₃ -N, mg/l	0.16	0.34	0.80	0.09	0.40	0.14
Total N, mg/l	-	-	-	-	-	-
Total PO ₄ , mg/l	-	-	-	-	-	-
Sol., PO ₄ , mg/l	-	-	-	-	-	-
ABS, mg/l	2.8	2.5	1.8	2.1	2.7	-
Coliform/100 ml	33	3300	460	12	460	700

¹ Estimated

TABLE XV

Bottom Deposit Solids

Time Collected	Location	Station	Ash Percent	Volatile Solids Percent
Spring, 1964	Barr Lake, 1/4 Point	511	49	51
Spring, 1964	Barr Lake, 1/2 Point	512	88	12
Spring, 1964	Barr Lake, 3/4 Point	513	89	11
Spring, 1964	Barr Lake, 4/4 Point	514	72	28
Late Summer, 1964	Barr Lake, 3/4 Point	513	79	21
Late Summer, 1964	Barr Lake, inlet	510	81	19
Late Summer, 1964	Barr Lake, shoreline ¹	-	99	1

¹ Sample collected on sandy bottom, away from sludge beds

General sludge deposit observations:

- a. Burlington-O'Brian Canal: 6-14 inch deposit septic sludge on bottom for most canal length.
- b. Lake bottom is sandy. Sludge deposits generally confined within the 5070 contour (550 acres) and range in depth from 0.5 - 6 inches.

It is probable that a mass emergence of adult midge flies from the sediments could produce pronounced nuisance conditions around the Lake.

A reduction in the deposition of organics to the Barr Lake sediments could result in more midge flies because of more tolerant conditions or it could result in fewer midges because of the establishment of predators and competitors for food. The long period of zero dissolved oxygen in Barr Lake and Lake drawdown now results in the destruction of bottom organisms between summer seasons. If this destruction ceases, other bottom organisms less tolerant of low oxygen levels may become established. It is probable that the numbers of midge flies will be reduced in the future.

Bottom Deposits (Table XV): Barr Lake has a sandy soil bottom most of which becomes exposed near the end of each irrigation season. Solids that settle to the Lake bottom and subsequently become dewatered, mineralize by bacterial action, desiccate in the sun, and essentially lose their identity prior to refilling of the Lake. Thus, sludge deposits on the Lake bottom are largely confined to that area of the Lake constituting the "dead water" pool which lies below the 5070 foot contour (about 550 acres or 3700 AC-FT). In this area the sludge depths range from a negligible amount to around four inches, a shallow organic sediment depth indeed for a lake. As represented in Table XV, these sludges average about 80 percent ash which indicates them to be rather well digested and typical of natural eutrophic lake sediments.

Examination of the Burlington-O'Brian Canal bottom by Public Health Service personnel disclosed a septic sludge in the canal which extended into the Barr Lake inlet, varying from 6-14 inches in depth.

Barr Lake Outlet, Station 515 (Table XIV): Samples collected from the Lake outlet at its point of discharge into the Speer Canal were essentially the same as those samples collected from within the Lake at station 514. Coliform bacterial values were low; nitrate values were relatively high for a surface water; and the BOD values, while much lower than the Lake influent, were still high for a normal surface water. The high suspended solids values are probably largely due to plankton. Detergent concentrations were high enough in the turbulent Lake discharge to send clouds of foam down the irrigation canals.

Biochemical Oxygen Demand Loading on Barr Lake: Tables V and VI present the mean monthly biochemical oxygen demand loadings on Barr Lake during the study period and probable mean monthly loadings during the period of 1953-63. The data used in constructing these tables was discussed in previous pages herein. BOD loadings are reported in monthly mean units of pounds of BOD per acre of prevailing water surface per day. These are 5-day 20°C BOD values. This unit of loading is used because it is the conventional unit used in waste stabilization ponds with which Barr Lake will be compared. A more appropriate unit for deeper bodies of water like Barr Lake may be lbs/acre-foot/day.

The probable calculated BOD loading on Barr Lake during the study period was zero in the no inflow months of July, August, September and February. In other months it ranged from a low of 0.8 to a high of 103 lbs/acre/day in May and December of 1964 respectively (see Table V). During the period of 1953 to 1963, the mean monthly probable loading (Table VI) ranged from a low of 4.9 to a high of 33.3 lbs/acre/day in July and October respectively.

These values are in general rather conservative if one were to compare Barr Lake with a waste stabilization pond (or lagoon)¹ operating as an aerobic, anaerobic, or facultative treatment device. Aerobic or facultative waste stabilization ponds are usually 2-5 feet deep and their treatment effectiveness as an aerobic unit is more a function of their surface area than their volume. Anaerobic ponds are usually somewhat deeper, say 5-8 ft. Aerobic pond units normally function without odors and with high (over 90 percent) BOD reductions with loadings under good conditions up to 60-70 pounds of BOD per acre per day, as widely reported in the literature. These units with the higher loadings are shallow, the water temperatures are relatively high, and are not subjected to prolonged periods of ice cover. Barr Lake is cold during the season when odors have been experienced; also, anaerobic water from the deeper portions is mixed into the upper portions producing a higher unit area oxygen demand. In the spring, because of its greater depth, Barr Lake will take longer to warm than would a shallower pond.

Studies were made of sewage stabilization ponds in the Dakotas by the North and South Dakota Departments of Health and the Public Health Service (9). Although the winter temperatures in the Dakotas are colder than those around Denver, the spring and autumn temperatures are similar and thus it might be useful to state the pond design criteria recommended for the Dakotas. Because of the climate, BOD loadings not to exceed 20 pounds per acre per day are recommended for the Dakotas. In the winter-spring transition period, the time from ice melt to the establishment of aerobic conditions and an absence of odor, varied from 3 days on a shallow pond with a BOD loading of 6 pounds per acre to 53 days with BOD loading of 28 pounds per acre per day. These Dakota ponds produced atmospheric odors generally only during the transition period from ice cover to a well established algal population.

It is true that the present BOD loading on Barr Lake per unit of Lake volume is low as compared to the Dakota lagoons because of its relatively large depth. However, in the Dakota lagoons, wind mixing

¹ It should be clearly indicated that Barr Lake is much deeper, much larger, and is operated in a different fashion from the normal waste stabilization pond. There do exist similarities however and this comparison is the best possible with present available knowledge.

will mix the entire lagoon contents and thus assist in reaeration, bring algae in contact with light, and it will disperse the food amongst the organisms. In Barr Lake, wind mixing is usually confined to the upper layers of water and anaerobiosis with its oxygen demand proceeds in the deeper waters essentially at all times. The period of transition in Barr Lake from ice cover to an odor-free water can be expected to take from 30-60 days under present conditions of BOD loading.

Other Waste Stabilization Pond Data: Stanley (10) reports that in Manitoba and Saskatchewan, BOD loadings up to 50 pounds per acre per day are allowed. Higher loadings may be allowed in Alberta if treatment requirements are not stringent. The odor nuisances have not been great even when anaerobic conditions existed for some time in these ponds. Localized sludge deposits on the pond bottoms did not produce any significant odor problems. Lagoons in Canada, according to Stanley, have generally caused less odor problems than the average sewage treatment plant. In Manitoba, ponds are now permitted within a few hundred feet of dwellings. Experience with anaerobic ponds in Alberta indicated that odor problems were not too significant. However, recommendations are that anaerobic ponds not be built near habitations.

Neel, et al. (11), in lagoon studies in warmer Missouri, found that about two weeks were required, with BOD loadings of 60 pounds per acre per day, to establish sufficient photosynthesis, after melting of the ice cover, to permit aerobic conditions. With BOD loadings of less than 20 pounds per acre, a fairly transparent ice, and little snow cover, there was sufficient photosynthesis to provide aerobic conditions under the low rate of bacterial metabolism. They recommend winter loadings of less than 20 pounds of BOD per acre and would even then anticipate zero oxygen levels under the ice and for a few days after the ice cover leaves. Some sulfide odor was reported after ice melt with loadings above 60 pounds and ice cover of over 30 days duration.

Mackenthun and McNabb (12) in a study of Wisconsin stabilization ponds report that odors were associated with prolonged anaerobic conditions. BOD loadings of less than 9 pounds per acre per day did not produce odors after removal of ice cover; loadings of 11 to 17 pounds produced detectable odors up to two weeks after departure of the ice cover; and up to four weeks of odors were detectable after ice melt with loadings of 22 to 26 pounds.

Bartsch (13) reports that ice cover from 9 to 27 inches can reduce light intensity from 75 to 99.5 percent and thus greatly impair the process of photosynthesis. In ice covered ponds, the dissolved oxygen may disappear rapidly followed by hydrogen sulfide formation which is trapped under the ice.

Horning, et al. (14), in a study of small waste stabilization ponds around Cincinnati, Ohio, loaded at rates of 59 to 132 pounds/acre/day in the winter, reported BOD reductions of 56-75 percent. Ice cover was present at times but did not persist long enough to produce odor problems, even though the ponds were entirely anaerobic for several days.

Summary-Present Condition of Barr Lake: Water quality conditions associated with Barr Lake may be summarized as follows:

1. The South Platte River upstream from the Denver North Side Sewage Treatment Plant discharge is polluted from a number of sources. It is anticipated that the majority of these will be connected into the sanitary sewer system before the new Metro plant is placed in service. River pollution is particularly significant during periods of low stream flow, usually December through February. Because of adequate natural reaeration, dissolved oxygen depletion does not appear to be a problem upstream from the Denver sewage treatment plant. Barr Lake water quality in the future could be significantly influenced by a continued degradation of these upstream waters due to population and industrial expansion. There should be a continual surveillance of the South Platte River water quality.
2. The primary source of pollution in the South Platte River, and in Barr Lake, is the partially treated sewage discharge from the Denver North Side plant. Discharge of organics from this source is well beyond the assimilative capacity of the South Platte River by any standard of water pollution evaluation. It is particularly severe during periods of low stream flow when the Denver effluent will exceed the natural stream flow in volume. It is during this period of low stream flow that a significant portion of the water is diverted for storage in Barr Lake.
3. Largely because of the Denver North Side treatment plant discharge of partially treated sewage, digester supernatant, and digesting sludge, the Burlington-O'Brian Canal becomes quickly devoid of dissolved oxygen below the intake and discharges a septic stream into Barr Lake at all times when this has been measured (see Table IX) and most probably at other times.
4. Barr Lake is filled primarily during the non-irrigation season in a normal year when a large portion of the filling water is sewage treatment plant effluent, water temperatures are low, and the biota are semi-dormant. After the ice leaves and the Lake commences to warm in the spring, anaerobic bacterial action accelerates on the entrained organics and it is probable that increased quantities of hydrogen sulfide are then produced by sulfate reduction in this relatively high sulfate bearing water. Algal activity remains at a low level because of cold water temperatures and a lack of light penetration due to a relatively

high concentration of suspended solids in Barr Lake. It is probable that odors may be concentrated and carried from the Lake during this period when atmospheric inversions are present and there is a breeze off the Lake.

With increasing water temperatures and water clarity resulting from microbiological action, algae begin to appear in large numbers and produce enough oxygen through photosynthesis to help maintain the surface waters of the Lake in an aerobic or near aerobic condition during the late spring and the summer with an absence of odor. In the autumn as water temperatures cool with a nearly empty Lake that is being refilled with heavily polluted water, there once more exists a condition for odor production until the water temperatures drop to the freezing level.

5. Sludge deposits in Barr Lake are minimal and of little overall significance. The sludge in these deposits, when examined, was largely digested and normal for an eutrophic lake.
6. Barr Lake provides a rather effective purification system comparable in some respects with a waste stabilization pond.
7. A comparison of Barr Lake with waste stabilization ponds, or lagoons, indicates that the present rate of BOD loading to Barr Lake is usually within normal BOD loading rates for typical facultative lagoons. When compared with operating experiences and loading rates for lagoons in areas of winter ice cover, it is evident that under present conditions odors will probably develop over a period of 30-60 days after the ice cover has melted. Odors may also be present prior to ice cover in the autumn when BOD loading rates are frequently high.
8. From an aesthetic standpoint, the appearance of Barr Lake is unacceptable. Also, the odors produced by Barr Lake have been intolerable at times. Odors in this area may also originate from a number of sources other than Barr Lake.

CONDITIONS EXPECTED IN BARR LAKE AFTER COMPLETION
OF METRO SEWAGE TREATMENT PLANT

After completion of the Metropolitan Denver Sewage Disposal District No. 1 (Metro) treatment plant in late 1966 or early 1967, the question must be answered on how this will affect water quality in Barr Lake. Will a general beneficial effect be noted immediately or will some time be required for the overall lake water quality to improve; and will this beneficial effect be sufficient to remove all possible odor problems within the near future after the plant is placed in operation. A positive answer cannot be given to these questions since there are many variables involved whose future magnitudes can only be given a predicted value at this time. The future quality of water diverted into Barr Lake will depend upon the rate of natural stream flow, the quality of the South Platte River water diverted into the Burlington-O'Brian Canal, and the quantity and quality of Metro effluent pumped into the canal during different seasons. Sufficient data are available or can be estimated, however, to permit a qualified evaluation on this future water quality.

The following conditions are taken for this evaluation:

1. Continuous and effective operation of the various sewage treatment facilities.
2. A BOD reduction of 80-90 percent in the new Metro treatment facilities that will produce an effluent whose BOD will have an average maximum value not to exceed 50 mg/l¹ (Denver has a strong sewage). "Design Criteria and Loadings", calculated by the Denver Metro Engineers, show a total raw sewage BOD of 256,000 pounds per day (this has been revised by recent additions to 270,000) for a design flow averaging 117 mgd (6). From these figures, it can be calculated that the average raw sewage BOD used in the design criteria is 262 mg/l. Overall plant performance or effluent standards are not stipulated in these design criteria. The raw sewage BOD of 262 mg/l is considered to be on the optimistic or low side.
3. No sludge or ash discharged with the effluent.
4. That liquid emanating from the sludge dewatering or disposal operations will be returned to the plant influent or the aeration unit influent.

¹ 50 mg/l is also the average maximum allowable BOD that can be discharged by State Health Department regulations and Colorado State law.

5. That Barr Lake will have been drawn down to its dead pool elevation in the first summer of full-scale Metro treatment plant operation.
6. That the pollution loading now carried by the South Platte River upstream from the Denver North Side treatment plant will be reduced by approximately 60 percent to where the mean stream 5-day 20°C BOD is about 6 mg/l.
7. That the same quantity of sewage treatment plant effluent will continue to be diverted by pumping into the Burlington-O'Brian Canal as at present in the autumn, winter and spring, to satisfy existing water rights (see Table II). (It is probable that less Metro plant effluent will be pumped than is assumed herein.)
8. That the future mean biochemical oxygen demand loading on Barr Lake will be as shown in Table XVI. This is considered to be on the non-optimistic side. With careful water control and good treatment plant operation, these values should be lower.

Table XVI indicates that the mean BOD loading on Barr Lake will be reduced to about 30 percent of the previous rate of loading (see Table VI) after full scale operation of the new Metro sewage treatment plant. During the months of April through August, when the South Platte River flow is normally high (Table II), it is rather probable that no effluent would have to be pumped to the Burlington-O'Brian Canal. This would be a definite factor in reducing the possibility of autumn odors in late October and November but would have little if any influence on the possibility of odors following the ice melt in March or early April.

Precise calculations cannot be made on the treatment processes taking place in Barr Lake, such as those proposed by Hermann and Gloyne (15), Oswald and Gotaas (16), or Rich (17). This is because Barr Lake is not a shallow even-depth lagoon, well mixed periodically by the wind; because input BOD values are approximated; and because the inflow, outflow, and water depths vary widely from month to month. It is possible to estimate the atmospheric reaeration rate and the oxygen requirements in the Lake following the ice break-up. It is then possible to estimate the time required to oxygenate the upper layer of Lake water to the point where odors are no longer released.

During the normal period of ice cover, late November to about the end of March, the 5-day 20°C BOD of water entering Barr Lake would average around 27 mg/l. Oxygen entering the Lake by advection and photosynthesis would probably not meet this demand. 5-day 20°C BOD removals under anaerobic conditions (if these prevail) range widely in anaerobic lagoons depending upon the type of waste, detention period, pond depth, and photosynthesis taking place (9) (11) (12) (14) (18) (19). Percentage removal values may range from about 50 to 75 percent. Barr Lake contemporary data indicate a removal of 60-75 percent in this period.

TABLE XVI
Estimated Future¹ BOD Loading on Barr Lake

	Estimated BOD in Burlington-O'Brian Canal 5-day 20°C mg/l ²	Thousand Pounds of 5-day 20°C BOD Added Daily to Barr Lake	BOD Added Daily to Barr Lake lbs/acre/day ³
Jan.	32	13.2	9.8
Feb.	28	8.7	6.0
Mar.	23	5.3	3.4
Apr.	17	4.9	3.0
May	12	3.5	2.4
June	13	4.3	3.2
July	17	1.6	1.5
Aug.	18	1.4	2.2
Sept.	23	2.1	3.8
Oct.	25	7.1	9.9
Nov.	24	9.0	9.4
Dec.	28	11.4	9.9

¹ By future is meant following construction of the Metro STP.

² Calculated from values in Tables II and IV assuming a STP effluent BOD of 50 mg/l and a South Platte River BOD of 6 mg/l. Both of these values were held constant.

³ Calculated using Barr Lake areas in Table IV.

Immediately following the future periods of ice cover in Barr Lake, we may then expect the Lake water to still have a 5-day 20°C BOD of about 10 mg/l if anaerobic conditions persisted.

Thus when the ice melts, it is probable that anaerobiosis will have been present in Barr Lake for a sufficient length of time to have produced appreciable quantities of sulfides which would continue to be liberated until aerobic conditions became established in the upper water layers during a portion of the daylight hours. In this transition period, the water temperature would probably average around 4-5°C (the deeper denser water at about 4°C would be mixed by wind action into the colder overlying water after the ice melt). At this temperature, the oxygen saturation deficiency to just maintain aerobic conditions would be about 11 mg/l and there would exist conditions for a maximum rate of oxygen transfer at the air-water interface. The rate of this transfer would be dependent largely upon wind action and would probably not be very effective at depths over 5 feet. Using Imhoff and Fair's approximation (20) for atmospheric reaeration,

$$R = 0.0271 (20) d (D_0)$$

R = reaeration in lbs/acre/day

d = basin depth in feet

D₀ = mean daily saturation deficit

$$R = 0.0271 (20) 5 (11) = \underline{30 \text{ lbs/acre/day}}$$

the maximum rate of oxygen transfer would be about 30 pounds per acre per day following the period of ice cover.

As previously indicated, the 5-day 20°C BOD of water entering Barr Lake at this time is estimated to be about 27 mg/l with an inflow averaging 43-54 cfs, taken herein to be 50 cfs or 32 mgd. Using the Phelps-Streeter formulations with a deoxygenation constant of 0.1 at 20°C and 0.05 at 5°C, the ultimate first stage 20°C BOD of the influent water is calculated to be 38 mg/l, or 28 mg/l at 5°C. It should be noted that the ultimate BOD at 5°C is less than that at 20°C. The daily oxygen requirement of this water is calculated to be $(28)(8.34)(32) = 7450$ pounds per day. In March the Lake area should be about 1575 acres (Table IV). Dividing 7450 pounds of oxygen required per day by 1575 acres, gives an oxygen demand on an areal basis of 4.75 (or about 5) pounds per acre per day for this inflow water.

Oswald (19) states that the maximum average oxygen saturation deficit to be permitted is 6 mg/l if odors are to be strictly avoided 24 hours per day. Based on an oxygen saturation level of 11 mg/l for the Lake, a minimum of 5 mg/l would be required in the Lake to prevent odors. At a net rate of oxygen transfer to the Lake of $30 - 5 = 25$ lbs/acre/day, 3-4 days would be required to introduce approximately 5 mg/l

of oxygen into the upper five feet of the Lake. The increasing oxygen content of the Lake would reduce the rate of atmospheric reaeration and the Lake would actually require a somewhat longer period for development of odor-free conditions.

From the foregoing it can be concluded that after the new Metro plant is in regular operation, Barr Lake will have water quality conditions conducive to odor production for a short period following the ice melt. This period may last for about one week or until photosynthesis is well established, which could require up to two to three weeks, as observed at other locations under similar conditions. One difficulty at present concerning the onset of photosynthesis is the unusually large amount of suspended matter in Barr Lake, originating apparently in a large degree from the discharge of sludge and other suspended material into the South Platte River. Cessation of these sludge discharges should provide better water clarity and a more rapid establishment of photosynthesis than in the past.

Bottom sludge deposits in Barr Lake are not extensive, the sludge is relatively well digested, and these deposits should not affect the overlying water quality any more than in a normal lake.

In the autumn, as water temperatures cool and stronger waste discharges are admitted to Barr Lake, there should not be a recurrence of odor conditions as in the past because of the lesser organic loading to be admitted to the Lake and the greater water clarity. The Lake will be entering this period with a much higher water quality than in the past, photosynthesis will have been established, and there will be no prolonged period of anaerobiosis before the ice forms.

Since Barr Lake is largely drained each year and because bottom deposits are not of any great significance, it should reach the conditions described above in the spring of the year succeeding completion of the Metro plant in late 1966 or early 1967.

A secondary cause of odor from Barr Lake could arise from the decay of large amounts of algae driven ashore by wind action. Increased water clarity in the future should produce greater algal blooms. Algal odors may also come from off the Lake itself. These, however, should not be intense and may be controlled by practical measures.

MEASURES THAT MIGHT BE USED TO IMPROVE FUTURE

BARR LAKE WATER QUALITY

If indeed Barr Lake does produce appreciable and prolonged odor nuisances in the spring of the year following completion of the new treatment plant, there are several things that might be done to alleviate the situation (see next section for additional discussion). The practical way to accomplish this is to lessen the organic load imposed on Barr Lake. This can be done by: (1) pumping only a minimum of Metro effluent to the Burlington-O'Brian Canal; some changes in water releases from storage and water allocations might be necessary; (2) by producing a high quality effluent from the Metro plant; with skilled and careful operation, this plant could effect a 90 percent BOD removal rather than the 80 percent assumed herein; (3) and by collecting or providing additional treatment to wastes entering the South Platte River above the Burlington-O'Brian Canal diversion. These latter two items should of course be done regardless of whether or not Barr Lake produces an odor problem. Continued development of the Denver area is going to impose increasing waste loads on the South Platte River and it will be necessary to effectively treat all waste discharge if the stream is to be maintained as anything but an open sewer. It should be pointed out that any odor problems that might emanate from Barr Lake are originated by upstream pollution and not be the Farmer's Reservoir and Irrigation Company.

INTERIM MEASURES FOR IMPROVING BARR LAKE WATER QUALITY

In the one-year period prior to completion of the Metro sewage treatment plant, there is little that can be done from a practicable standpoint in reducing odors that may come from Barr Lake. Barr Lake has been widely accused for causing intolerable odor problems in Brighton. There are also many other potential sources of odors around Brighton, such as the local irrigation ditches, the nearby feed lots, processing plants, and sewage disposal plants. One measure that should be taken at all times is the control of emergent littoral vegetation on the Lake. This serves as a harborage for mosquito breeding, it lessens reaeration from wave action, and it provides for the accumulation of floating scum and algae that will produce odors on decay.

Odors from Barr Lake could be prevented or lessened by reducing the organic waste input to the Lake or by introducing oxygen to the Lake water. With a clean shoreline and dissolved oxygen in the Lake water, odors would be absent. Chemical treatment to artificially introduce oxygen to the water (for a bacterial respiration oxygen source) through the use of sodium nitrate, or to arrest bacterial action through use of a bactericidal agent, would be extremely expensive and probably not very effective because of the difficulty involved in near continuous application to such a large body of water during the odorous periods and prior to ice melt.

Oxygen could be introduced to Barr Lake or the feeder canal through use of various aerating devices that provide water circulation as they introduce oxygen to the water. These aerating devices could be submerged perforated pipes or hoses carrying compressed air or they could be mechanical aerators operating from a float or platform. Based on work by Riddick (21), as much as 780 horsepower might be required on Barr Lake to operate these aerators for effective aeration. Other devices would require more or less power, depending upon the design. A conservative rule of thumb value used in aerated lagoons is 2 lbs of 5-day 20°C BOD removed per horsepower hour or about 50 lbs/day. With a Barr Lake BOD loading of 18,000 lbs/day in March and about a 75 percent 5-day 20°C BOD reduction, 270 horsepower would be required in special lagoons. Additional horsepower would be required for the BOD exertion beyond the 5-day period.

Aerators installed in the Lake would probably prevent the formation of ice cover in the deeper portions of the Lake and thus permit reaeration and photosynthesis in this area if operated for most of the autumn, winter and spring. Aerators installed in the Burlington-O'Brian Canal itself would not reduce the BOD enough to have a significant effect on the stored Lake water. Aerators in the Lake might be considered at some future time if other measures of odor control are not successful. However, at this stage in the problem alleviation, it would require an unjustified expense and a considerable period of time to design and install these aerators.

Use of the Burlington-O'Brian Canal as a series of oxidation ponds with control devices would not be effective unless the channel was enlarged to provide a total detention period of at least 20-30 days in ponds having a depth of about four feet. With Barr Lake inflows of 50-80 cfs in the problem period, this would involve enormous pond acreages, say 800 acres at least. The algae and bacterial cells produced in the ponds would also have to be kept out of Barr Lake, a difficult task, for they themselves would exert an oxygen demand on Barr Lake. The ponds would also have to be kept free of ice in the winter period for effective operation.

Treatment of the canal water through installation of aerating devices would not be effective unless control was effected to where sludge could be generated, removed by sedimentation, and recycled back to the influent, as in the activated sludge process. Provision would have to be made for excess sludge disposal. This is controlled sewage treatment and it should be carried on at the sewage source. Short-period, simple aeration in the canal would have little beneficial effect in consideration of the long detention period provided by Barr Lake.

In the interim until the Metro plant is under operation, the advisable course of action is to operate existing treatment plants to the best of their ability, monitor the River for wanton waste discharges, cease the discharge of all sludge and other solids to the River, remove littoral vegetation from Barr Lake on a routine basis, and check on other possible sources of odors in the vicinity of Brighton that may be corrected through improved housekeeping.

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